The Superheterodyne Receiver

LESSON ND-22

SPRAYBERRY ACADEMY of RADIO

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PUEBLO, COLORADO

THE SUPERHETERODYNE RECEIVER

LESSON ND-22

Receiving circuits which have been popular in the past have been given descriptive names which serve to identify them. Only three types of circuits have enjoyed wide and popular use. These are the Neutrodyne, Tuned Radio Frequency and Superheterodyne. Of these three the superheterodyne is the most popular today and will probably remain so for a long time to come—at least until some better type of receiving circuit is discovered.

In the neutrodyne type of receiver, the common type of triode tube was used. The tuned circuits of this type of receiver will go into oscillation because of the capacity existing between the elements of the triode tube. This principle is explained in your lesson on high frequency amplification. The normal capacity between triode tube elements can be effectively cancelled or neutralized by means of a condenser, as explained in a former lesson. Because of the neutralizing effect, the name neutrodyne came into being to describe this type of circuit.

In spite of the apparent success of effectively neutralizing internal tube capacities, this arrangement ultimately had to give way to progress when better circuits and tubes were developed. Thus, the neutrodyne gradually gave way in favor of the *tuned radio frequency* type of receiver. This type of circuit using screen grid tubes, enjoyed several years of popularity and is still used today in some very small receivers. In addition, most modern superheterodyne receivers employ one or two stages of TRF amplification in the receiver. This section of a superheterodyne is called a *preselector,* and you will learn more about it later on in this lesson.

The basic superheterodyne principle was developed principally by Major E. H. Armstrong in World War I (the same man who was later to play the principal part in the development of Frequency Modulation). However, the superheterodyne did not come into wide use until years later because of a peculiar patent situation. Thus, while this principle of reception is, perhaps, as old as the TRF, the latter preceded the former in wide use by many years.

As stated, the TRF tuning or preselector system is a part of almost every present day superheterodyne. So it is just a step from a consideration of the TRF receiver to that of the superheterodyne (hereinafter called the *super*). From this

you should understand why it is so important for you to learn the basic principles of previous lessons so thoroughly—it all ties in with other more advanced principles. So if you have any doubt about your understanding of TRF principles, now would be a good time to review these principles before taking up the study of the super.

The name heterodyne came into being because of the meaning of two Greek words—hetro, meaning to combine or mix, and dyne, meaning power. These together mean to combine power or energy, and the word super is included because such superior results are obtained when the heterodyne principle of reception is employed—thus, the word superheterodyne has come into wide use to describe a particular type of receiving circuit.

All receiving circuits in common use before the super had certain undesirable limitations. Among these were a lack of sensitivity, selectivity and amplification. Chief among these was a lack of selectivity and amplification. The older neutrodyne and TRF simply would not select signals adequately from different stations at adjacent carrier frequencies. Also, the amount of gain or ampification will vary considerably between 540 and 1600 KC. *The super overcomes this by amplifying all signals at a fixed frequency,* as you will learn later on. Another point in favor of the super is, because of its high gain, it will respond to very weak signals which would not be perceptible on a neutrodyne or TRF circuit. Thus, by using a super, the sensitivity of a receiving circuit is greatly improved. By one stroke, then, the super gives great improvement in three major properties of a receiving circuit.

These are clear advantages that the super offers over other types of receiving circuits. From this, however, you should not get the impression that the super is perfect. It, too, has its limitations and is a delicately balanced system. Minor variations and adjustments will greatly affect its operation. It is a scientific device and must be so regarded at all times—something you will appreciate more when you have a better understanding of the circuit and when you get to working with this type of circuit.

In the lesson on high frequency amplification, you learned, as a principle of tuned circuits, that a single triode tube, for example, would give a gain of 9.1 at 2000 KC, 6.9 at 1000 KC and 4.5 at 500 KC. The principle reason for this variation in gain is the fact that the tuning circuit must, of necessity, cover a wide band of frequencies. For the broadcast band, this band coverage is from 540 to 1600 KC, or a ratio of $\frac{1600}{540}$ or 2.9. The tuning circuits are so arranged that the inductance values are fixed and remain at this one value. The tuning condensers, on the other hand, are variable. Thus, at 1600 KC there is a minimum of capacity and the inductance predominates. At 540 KC there is a maximum of capacity with the result that the capacity predominates. For every frequency to be received there is an ideal value of inductance and capacity to give the desired characteristics for that one frequency.

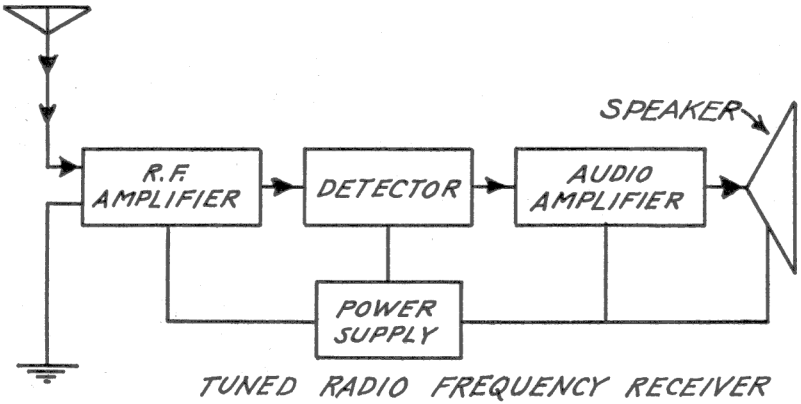
This ideal is derived from the LC ratio of a tuned circuit. Thus, if the entire TRF tuned stages are depended upon to furnish *all the RF amplification* for the broadcast band, only those frequencies near the center of the broadcast band (around 1000 KC) will have the ideal load characteristics—that is, values of inductance and capacity which result in reactance values most suitable for the particular circuit.

The LC ratio is determined by multiplying the inductance in microhenries by the capacity in microfarads. The LC ratio ot 1500 KC is .01126. At 1000 KC it is .0253, and at 600 KC it is .0704. If a fixed inductance of 275 microhenries is used to cover the band from 1500 to 600 KC, the capacity value needed at 1500 KC will be $\frac{.01126}{275}$ or .0000409 mfd. At 1000 KC the needed capacity value will be $\frac{.0253}{275}$ or .000092 mfd. At 600 KC the needed capacity value will be $\frac{.0704}{275}$ or .00025 mfd. Hence the variation is self-evident. Because of the fact that tuning over a wide band of frequencies is desirable for a given receiver, this condition of an unbalanced ratio of capacity to inductance *must be tolerated.* However, it may be largely corrected in the super circuit because it is possible to amplify all received signals at *one fixed frequency.* In this case, ideal values of inductance and capacity may be chosen for a given tube and type of circuit. Because of this, maximum gain may be obtained for all signals which is not true, as you know for TRF and neutrodyne circuits.

Since this lesson is devoted to super principles, the details of LC ratios and other related factors such as the Q of tuned circuits will not be taken up in this lesson, but a later lesson will go into these things thoroughly. The purpose of the brief foregoing reference to LC values is to show how *gain varies* over the tuning band in a TRF or neutrodyne circuit. With these limitations definitely in mind, you can better appreciate the virtue and need for the fixed frequency amplifier in the super which is better known by the name of intermediate frequency (IF) amplifier.

You will remember that several stages of RF amplification are employed in TRF and neutrodyne circuits. When the signal has been built up to the disired level, it is then fed to a detector which, in turn, feeds it to the AF amplifier; from thence it goes to the speaker. *In the super circuit, the important difference between it and the TRF type of circuit is that within the receiver the carrier frequency is changed to another value.* Basically, this is the only real difference. However, because the carrier frequency is changed, *several new circuit elements must be employed* which are not present in the TRF circuit. These new circuit elements which have not been described in your SAR Course up to now are listed as follows in the order in which they affect the signal.

(1) Local oscillator—meaning a tube arranged to generate a pure unmodulated RF energy of its own accord. (2) A first detector, mix-

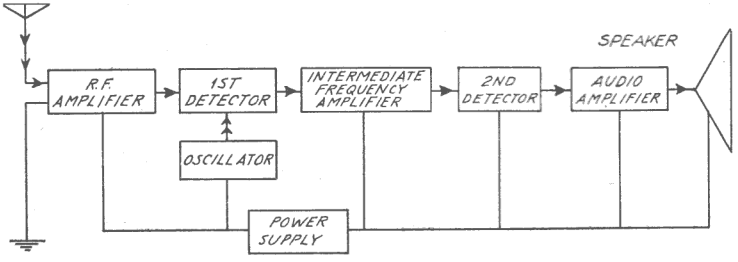


TUNED RADIO FREQUENCY RECEIVER

FIG. 1

er or converter—all terms meaning the same thing. This is a tuned circuit with a tube which accepts at its input the received signal from the antenna or preselector stage or stages *plus* the RF energy from the local oscillator. Thus, this tube takes two RF impulses at its input and delivers a new type of signal at the output of the same tube. (3) The intermediate frequency amplifier—this is the fixed frequency amplifier which accepts the new type of signal from the output of the mixer tube. (4) The second detector—this is a one tube stage which accepts the signal from the IF amplifier, removes the new RF carrier and feeds the signal on to the AF amplifier just as in any receiving system. Thus, in studying the super circuit, you will need to learn the details of four more circuit elements. That is all there is to it, and if you make sure to understand the basic elements as you go along, you will not have any trouble.

A block diagram is sometimes very useful in showing basic principles because it can illustrate these principles without bringing in confusing details Such block diagrams are shown in Figs. 1 and 2. In Fig. 1, the general system of the TRF circuit is shown. Arrow heads indicate the direction in which the signal passes through the receiver. Study this block diagram until you get a mental picture of what takes place. Now refer to Fig. 2. This shows the super principle, and, in this case, arrow heads again indicate the direction



SUPERHETERODYNE RECEIVER

FIG. 2

in which the signal progresses through the receiver. Note the RF amplifier feeds the 1st detector and note, too, the oscillator feeds into the 1st detector. From the output of the 1st detector the progression of the signal is to the IF amplifier, the 2nd detector, AF amplifier and, finally, the speaker. Study both Figs. 1 and 2 carefully until you have memorized the basic elements of the circuit and the way the signal progresses through the various circuit elements. This will help you to get a quick understanding of the details of each circuit element.

THE PRESELECTOR OR RF AMPLIFIER

It is not essential that an RF amplifier or preselector precede the 1st detector or mixer tube. This section of the super circuit may be and often is omitted in low price receivers. Where it is omitted the selectivity is much poorer than when a preselector is used. When engineers have to build a receiver down to a price level rather than up to a quality level, the preselector is usually left out. If no preselector is used, the signal energy is usually directly coupled into the input of the 1st detector. When a preselector is used, it affords a large measure of selectivity and some added sensitivity over that obtained with no preselector.

Regardless of whether or not a preselector is used in either case the received signal energy is fed to the input of the 1st detector, there to be combined with the local oscillator energy. If a preselector is used, it will be very similar to the TRF circuits which you have previously studied with, of course, suitable coupling to the 1st detector. More details of the preselector will be presented later.

THE FIRST DETECTOR OR MIXER OF THE SUPERHETERODYNE

It is a fact that there can be but *one voltage value* between any two points of a circuit at any *one* instant. If two or more voltages are applied to a single circuit, they will add or subtract or will stabilize at a higher, equal, lower or zero voltage. In the case of the 1st detector or mixer, the objective is to bring or mix together in series, *two* high frequency voltages (one the received signal from the preselector and the other the local oscillator RF energy). Of course, if the two voltages are of the same values and in *phase,* the result will be the *sum* of the two or simply as though one had been amplified to twice its value. However, if one is different in frequency from the other, a very unusual condition may result in the circuit.

A simple example will make this clear. Refer to Fig. 3. In this assume that two circuits, A and B are coupled to a third circuit, C. This will duplicate the conditions in a mixer circuit. Circuit A of Fig. 3 oscillates at 6 cycles per second while B oscillates at 7 cycles per second. *In one second,* circuit C and its load, R, will receive 6 cycles from circuit A. This will be induced into coil L_1 to which A is coupled. During the same time 7 cycles will be induced into the same circuit C through L_2 from circuit B. Either of these two voltages alone would, if impressed across

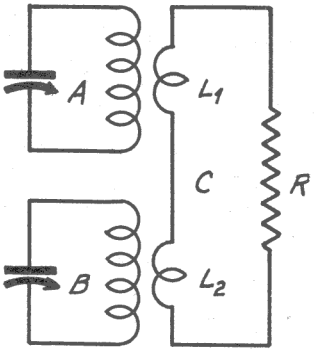


FIG. 3

R, appear as indicated by the *dotted line* curves of Fig. 4, if represented graphically. Study this figure carefully and identify the 6 and 7 cycle wave forms. Do not consider the *shaded* wave form at this time as it will be described later. In the first cycle, both voltages advance upward in the same direction but the 7 cycle voltage will reduce to zero a trifle before the 6 cycle voltage. This is because it is *changing faster* than the 6 cycle voltage. At the end of one cycle of each voltage, one will have covered 1/6th and the other 1/7th, of the total time illustrated by the horizontal length of the graph.

The difference between them is 1/6 − 1/7 = 1/42 of a second As time progresses, the 7 cycle wave will progressively fall behind the 6 cycle wave. At the end of 3 cycles of the 6 cycle wave and $3\frac{1}{2}$ cycles of the 7 cycle wave, the two will be acting in *opposition* to each other. You will recall how two voltages with *opposing polarities* will *cancel* each other and so it is with these two induced voltages. As the 7 cycle voltages successively lag behind the 6 cycle voltage variations, every 3 cycles of the 6 cycle voltage will be opposite in phase, or 180 degrees out of phase, to the 7 cycle frequency. When they are exactly in phase, their effects add, but as their *phase relationship* changes they gradually *counteract* each other until, when out of phase, *they completely cancel or neutralize each other.* The solid line (shaded curve) of Fig. 4 represents the resultant of

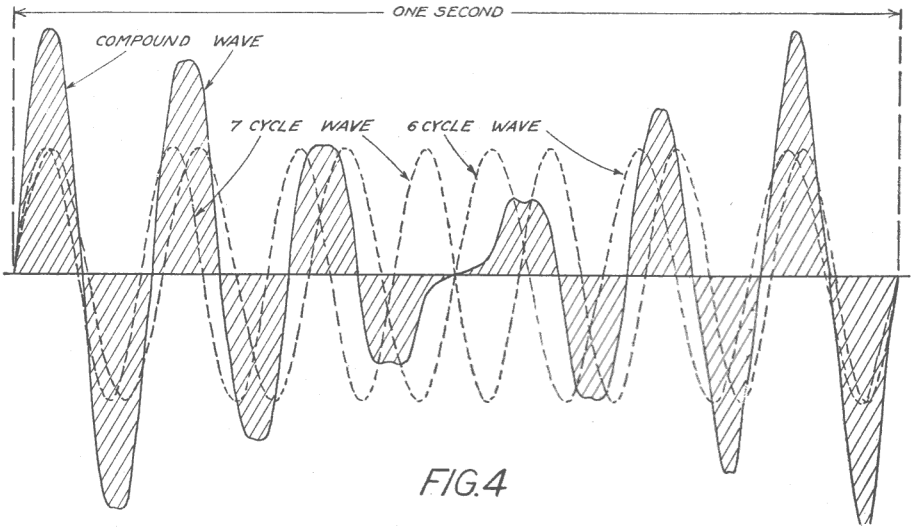


FIG. 4

the 6 and 7 cycle wave forms impressed across resistor R of Fig. 3. Though there are apparently only 6 cycles of this resultant wave, notice in Fig. 4 that its *frequency is not constant.* From the left end of Fig. 4 to the middle it requires more and more time for each cycle. From the middle to the right end each cycle is compressed into less and less time. Actually this resultant frequency starts at 7 cycles per second and tapers to 5 cycles per second at the center, thus swinging back and forth in frequency. Furthermore, you may notice that at the center the wave form is somewhat distorted and this becomes less noticeable at either end. Analyzing this wave form more thoroughly, you will find that there are also *13* peaks due to the spacing of the 7 and 6 cycle waves. As the two waves are continuously changing their relative spacing (phase relationship) this 13 (7+6) cycle wave does *not* exist when the peaks are exactly together or when they are exactly opposite one another but *only* when they are somewhere between the two points. You can see that there are 13 peaks of the two dotted waves (6 and 7 cycle wave forms) at the top and as many at the bottom of Fig. 4. This makes 13 cycles as one positive and one negative alternation comprise one cycle. Moreover, it may be easily seen that the *amplitude* of the solid line curve is maximum at either end, reducing to zero at the center. If this were *rectified* by a detector the *average output* would equal *one* cycle as indicated by the heavy dotted line of Fig. 5. *Without rectification* only the resultant *solid line* curve in Fig. 4 would result. This indicates a frequency varying between 7 and 5 cycles but being more *powerful* at one instant than at another. The change in average intensity, due to rectification, occurs at *one* cycle per second. (7−6=1). There is also another frequency present in Fig. 4 equal to 7+6 or 13 cycles but the equivalent wave form of this frequency is not shown in Fig. 4 in order to keep the wave forms as simple as possible. This refers only to this example. *The same principle would apply to any other two frequencies which are combined in the manner described.* If the time interval, represented by the base line in Figs. 4 and 5, were *one microsecond* instead of *one second,* it is obvious that that the frequencies would be 6,000,000 cycles (600 KC) and 7,000,000 cycles (700 KC) instead of 6 and 7 cycles. The resultant *frequencies* in this case would be 1,000,000 and 13,000,000 cycles after rectification and filtering.

This method of combining fre-

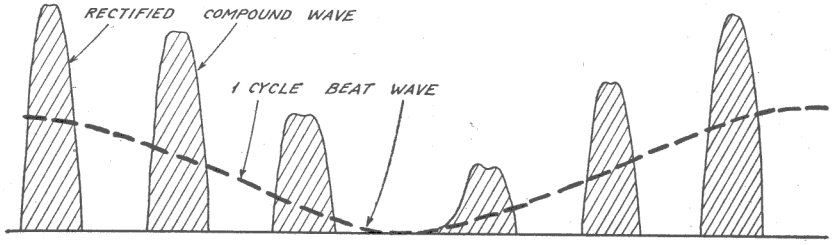


FIG.5

quencies in a mixer tube of a super is called heterodyning or beating frequencies to produce resultant frequencies.

The following facts become evident from the study of the examples given.

1. When two different frequencies are combined in a mixer circuit, a *third and fourth* frequency will be created. These are called *beat frequencies* (as a result of hetrodyning).

2. These two beat frequencies are *not* constant in *amplitude* or *frequency.*

3. These *new* beat frequencies, change from the value of the *highest original frequency* to a value as far *below* the *lowest original frequency* as the highest one is above it.

4. The *amplitude* of the beat frequencies varies from an amount equal to the sum of the amplitudes of the original frequencies to an amount equal to the differences in their amplitudes, when they have *different peak values.*

5. The amplitude of the beat frequencies varies from twice the amplitude value of the original frequencies, to zero when the amplitude of the original frequencies *are of equal value.*

6. This *variation* in *average* amplitude occurs at frequencies equal to the numerical *sum of* and *difference between* the original frequencies.

It is *very* important for you to realize and to understand just what happens when two frequencies are combined to form other frequencies. Always remember that when two frequencies are hetrodyned, *two new* frequencies are created. *Each* of these two new frequencies can only have *one certain value.* This value *always* bears a direct relation to the two original frequencies. This relation may be stated as follows: two original frequencies, when properly combined will produce two beat frequencies. These two beat frequencies are known as the *sum* and *difference* frequencies. In the case of the previous example, the *sum frequency* is equal to 7+6 or 13 cycles. The *difference frequency* is equal to 7 − 6 or 1 cycle. The same principle holds true for any other two frequencies. For example, if we combine 1000 KC and 1456 KC, the sum frequency equals 1000 + 1456 or 2456 KC. The difference frequency will equal 1456 − 1000 or 456 KC. In practice, the modern superheterodyne makes use of *only* the *difference frequency* for reasons which will be explained later. Be certain that you clearly understand these hetrodyning facts as you will have many future uses for them.

The result of hetrodyning two frequencies is often called a *beat note* or beat frequency. When used in a superheterodyne receiver, one of the new or resultant beat frequencies is called the *intermediate frequency.* (IF)). This is because its frequency is intermediate between high or radio frequency and low or audio frequencies. You should understand that if one of the original frequencies is *modulated, the resultant beat frequencies will also be modulated.* The modulation of these beat frequencies will be identical to the modulation imposed on the original frequency.

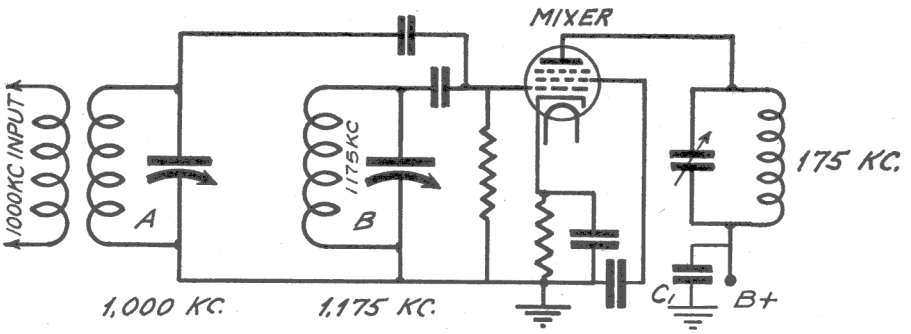


FIG. 6

To progress now into the manner in which the hetrodyning principle is used in receiving, refer to Fig. 6. Assume circuit A to be coupled to the output of an RF amplifier and that a modulated carrier of 1000 KC is being received. Assume, also, that circuit B is being excited at 1175 KC. As both circuit A and B feed the *grid* of the *mixer* tube, both frequencies will affect the electron flow to the plate. Thus, in the plate circuit a 175 KC (*difference frequency*) and a 2175 KC or *sum frequency* will appear. Notice that the plate circuit is tuned to 175 KC. This becomes the *intermediate frequency,* and all other frequencies will be filtered out by condenser C1 and only the 175 KC beat frequency will be passed on to the following *intermediate frequency amplifiers* (not shown in Fig. 6). The circuit in the plate circuit of Fig. 6 could be made to accept only the *sum* frequency of 2175 KC, and this could be used as the intermediate frequency just as well as the 175 KC value. However, it is possible to build a 175 KC tuning unit much more economically and easily than a 2175 KC tuning unit. These intermediate tuning units are usually called IF (intermediate frequency) transformers. It is far more practical to build these IF units to provide an *extremely high gain per stage* with very good selectivity when they are designed for 175 KC than it is at 2175 KC. This, and other reasons to be explained later, is why the lower of the two beat frequencies is used in most superheterodyne receivers. One of the original frequencies is, of course, the received signal. The signal and the local oscillator frequency are combined and rectified by the *first detector,* or mixer tube, and the beat note, or IF, is produced in its plate circuit. The *two original* frequencies as well as the sum and difference beats and the compound frequency appear in the plate circuit of the tube in which they are mixed. The plate circuit is tuned to only *one* of these frequencies, as in Fig. 6. For this reason the other frequencies are lost and the desired one carried on to one or more IF amplifier stages. The impedance of the plate tuned circuit to frequencies other than 175 KC (the IF) is such that all other frequencies are not amplified. This is the basic principle on which all mixer or 1st detector stages operate in super circuits.

THE SUPERHETERODYNE OSCILLATOR

You are now ready to study the operation of oscillators as used in super receivers. Here you will find that *unmodulated* carrier waves similar to those produced by a radio transmitter are generated by the oscillator. As you have learned, oscillation can be produced in an amplifier stage due to the *feed back* from plate to grid within a tube. While this oscillation would not be suitable for use in a *mixer,* the principle can be put to use so that the oscillations can be produced and controlled at will.

An oscillator is a *combination of circuit and tube* constants which will convert D.C. into A. C. When used in the super type circuit an oscillator converts the D.C. high voltage from the power supply into high frequency or RF.

The first oscillator to be studied is the simple inductive feedback oscillator. Illustrated in Fig. 7 is a very common and universally used circuit. This employs a tuned grid circuit with a grid leak and condenser wired exactly as it would be for detection. Added in the plate circuit is an untuned tickler coil which is magnetically coupled to the grid coil. The plate coil is called the *tickler* or *feedback* coil and is similar to those you have studied in regenerative detectors. Variations in the plate coil current magnetically *induce* voltages in the grid coil. This, in turn, causes a *change* in the *grid potential* which will cause another change in the plate coil, and so a varying condition will automatically be maintained. These variations will be of the frequency at which the *tuned grid coil resonates.* From a D.C. viewpoint, this circuit is very unstable. This is because it has no definite plate circuit resistance. However as the tube is placed in an operative condition, the flow of plate current will produce a change in the grid voltage. This change in grid voltage will change the plate to a new value. This new change in plate current will again affect the grid voltage which will cause a different grid voltage and so on. Since there is no *fixed* resistance in the complete plate circuit, the current will vary unstably. Thus, the circuit is termed unstable. When oscillating, however, the circuit becomes stable due to the fixed characteristics of the *tuned grid circuit* when carrying an oscillating current. This circuit action may be compared to the behavior of a toy *top.* It is practically impossible to make it stand on its point when stationary, but when spinning, it will automatically stand and becomes *stable.* The rate at which energy is transferred from the plate to the grid depends almost entirely on the coil and condenser values of the *tuned grid circuit.* If this circuit is supplied with electri-

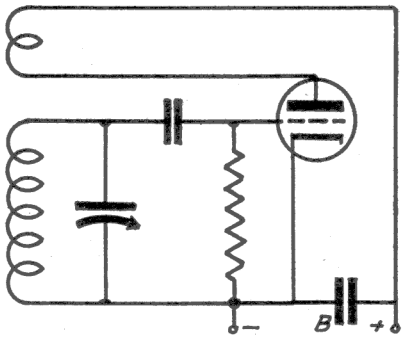


FIG. 7

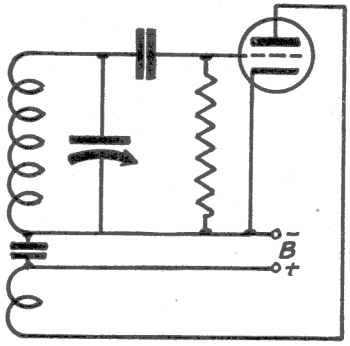


FIG. 8

cal energy from *any* source, the condenser will discharge into the coil at a *definite* rate and the field of the coil will build up and collapse at a definite rate. Other factors, such as tube and circuit *capacity* and the mutual inductance between the plate and grid *coils,* contribute to the total LC value. It is this *total* value which determines the frequency of oscillation.

While a circuit, such as this, will actually perform detection, that is not the purpose of the grid leak and condenser. They are in the circuit to produce an *automatic* bias on the grid of the tube so that the circuit will be *unstable* at the start and thus allow it to start oscillating easily. This bias is automatic and will adjust itself for any frequency to which the oscillator may be tuned. You have already studied how a grid bias is produced by modulation voltage variations in the lesson on detectors. In oscillators there is *no* modulation; however, the *grid swing* or voltage variation is much greater. Therefore, the bias is greater. The grid resistance or *grid leak* is *smaller* in value for the oscillator than for a detector. This is because the current is greater and the frequency at which the *grid condenser* must discharge is *higher*. The average value of these grid resistors for oscillators is about 50,000 ohms.

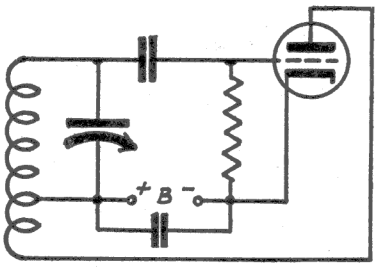


FIG. 9

The plate coil may be placed at either end of the grid coil. Figure 8 shows the plate coil placed at the cathode end of the grid coil. Electrically, the circuit is identical to Fig. 7 and functions in the same way. This circuit may be further simplified, as in Fig. 9, by combining the plate and grid coils. The operation of the circuit is still the same. Instead of separate grid and plate coils, use is made, in this case (Fig. 9), of an *autotransformer,* the lower section acting as a primary (or tickler) and the upper section as the secondary. Further simplification is obtained by tuning the *entire* autotransformer as in Fig. 10. Furthermore, since it is possible to introduce the *plate supply* at any point in the *plate circuit,* further simplification results

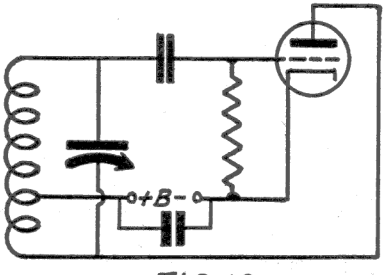


FIG. 10

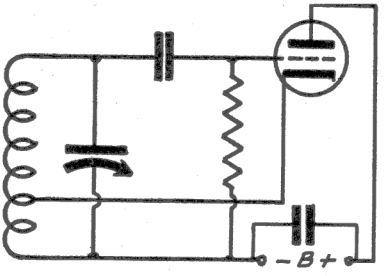


FIG. 11

in the circuit shown in Fig. 11. Note that the circuit action is the same for *all* of the circuits illustrated in Figs. 7, 8, 9, 10 and 11. In the latter three circuits the grid condenser also functions as a *blocking* condenser serving to isolate the plate positive potential from the grid of the tube.

Both the circuit shown in Fig. 11 and that in Fig. 7 are used extensively in modern super receivers. As you have no doubt observed, any of these circuits will act as detectors. They will also function as detectors while oscillating. This is made possible by simply introducing a signal carrier of one frequency into the circuit while it is oscillating at another frequency. A circuit *combining oscillation and detection* is called an *autodyne* and is used extensively in small *radio telegraph* code receivers. These are used for the reception of *ICW* or *interrupted continuous wave signals.* Since this type of dot and dash signal is *not* modulated, some means of making it audible is desirable. A very simple circuit of this type is illustrated in Fig. 12. The tuning condenser is adjusted so that the circuit is oscillating at 7210.5 KC for the reception of a signal of 7210 KC. Since there is a difference of .5 KC or 500 cycles between the signal and oscillator, there will be a 500 cycle beat tone or beat frequency heard in the headphones. When receiving such a signal, if the tuning condenser is varied, the beat frequency will also vary as *it is always equal to the sum or difference between the incoming carrier frequency and the local oscillator frequency.* The oscillation within the circuit produces an RF voltage across coil L2, of Fig 12. The voltage from the antenna circuit is also induced in L2. These *two* frequencies are simultaneously detected by grid detection and the beat frequency results in the plate circuit and headphones. You may observe that the tuned circuit is *almost equally resonant* to the two high frequencies as they are almost the same in frequency. The higher frequency is only .007 of 1% greater than the lower frequency. In this way the desired signal is tuned in while adjusting the oscillator so that there will be an *audio frequency* beat between the two. This will *not* do for the reception of radio telephone signals since it is not desirable to hear the beat frequency in this case. Instead it is convenient to use a beat frequency of 175 or 200 KC as a carrier of audio frequencies just as a broadcast station signal acts as a carrier for the modulation. From your past studies, it is evident that if the signal and local oscillator frequencies differ by 200

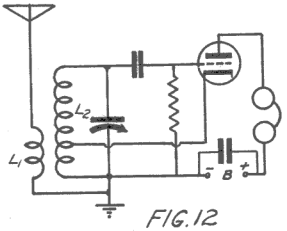


FIG. 12

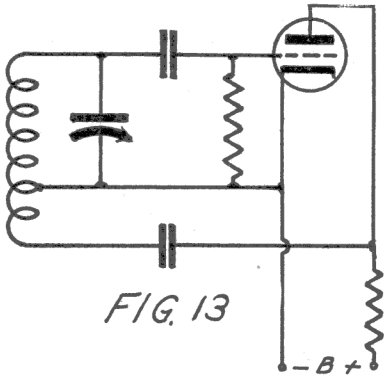


FIG. 13

KC, one circuit cannot tune to both of them at the same time. They must, then, be introduced into the detector or mixer from two separate circuits. For radiotelephone reception, the portion of the tube circuit used as an oscillator should not also operate as the mixer as it cannot perform both of these functions unless operated in a very critical or unstable condition. This would *not* be a satisfactory procedure for broadcast or *voice* frequency reception.

In all the circuits from Figs. 7 to 11, the plate current actually flows through the plate coil. In most receivers this would be objectionable. This is because the cathode network, condenser rotors and other circuit elements might require a connection to ground. In such cases the plate coil may be *shunt fed* as in Fig. 13. Here the plate *voltage variations* are fed to the plate portion of the tuning coil by a condenser. The positive voltage, however, is isolated from the other elements by this same condenser.

For the advantage of frequency stability, the circuit of Fig. 14 is sometimes used. The tuned circuit (L1C1) in this case is a separate *link* circuit to which the *untuned*

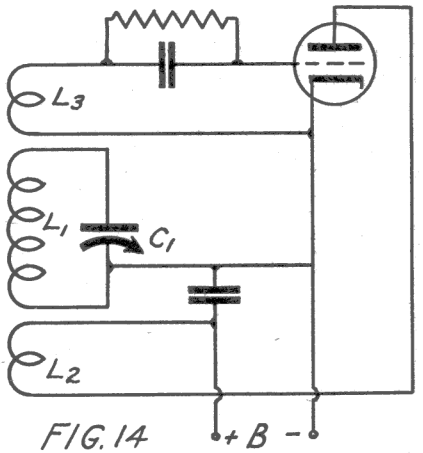


FIG. 14

plate (L2) and grid coils (L3) are coupled. Its operation is similar to that of Fig. 7 in that the plate coil (L2) *induces* a voltage in the tuned circuit (L1C1). The tuned circuit induces, or drives, the grid coil (L3) due to magnetic coupling between the coils. These three coils act as any other transformer functions.

In many cases—for example, police car receivers, jewelers' time signal receivers and aircraft navigation communications—the receiver will be *tuned* or *fixed* to one single frequency. The oscillators in receivers used for these or similar services are often of the *crystal controlled* type. This is because the *crystal* allows very accurate and constant frequency control.

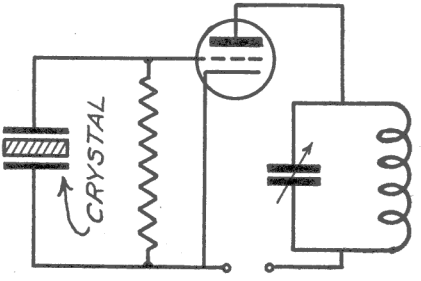


FIG. 15

This system is shown in Fig. 15 and is called a crystal oscillator. A thin *slice* is cut from a quartz crystal. By properly grinding the parallel surfaces of this slice it may be made to vibrate at one single RF frequency. In other words, if the crystal is clamped between two small plates of metal and a charge is placed across these plates, the crystal will *contract* and *expand* at a certain rate, depending on its thickness. When the crystal expands or returns to normal shape, it will return to the circuit another voltage, oppositie in polarity to the original charge. This action is similar to the action of a condenser. In addition to the dimensions of the crystal, its *temperature* also governs its frequency to a large degree. As voltage surges or pulses are fed to the grid they are amplified and produce larger changes in the plate circuit. These larger plate impulses are fed back to the grid by means of the grid-plate capacity as explained in an earlier lesson. Note that in this crystal oscillator circuit the *feed-back* energy is not supplied to the grid *magnetically* but by means of the *internal grid to plate* capacity. The grid leak closes or completes the grid to cathode circuit and provides the bias for the grid.

Another popular oscillator circuit the *dynatron* and is shown in Fig. 16. The dynatron oscillator exhibits a characteristic called

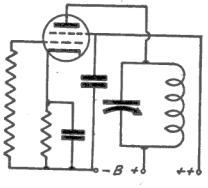


FIG. 16

negative resistance. When a screen grid tube is operated in a dynatron circuit a higher voltage is applied to the screen than to the plate. The electrons leaving the hot cathode are drawn to and accelerated by the screen. Some of these electrons fly through the spaces of the screen and impinge on the plate. The *surface* tension, which holds the electron structure composing the plate material within its surfaces, is thus *disturbed* by the high speed electrons from the filament. The velocity of the arriving high speed electrons is sufficient to *splash* or release *other electrons* from the plate. These released plate electrons form what is called *secondary emission*. Because the screen is at a higher positive potential than the plate most of this secondary emission will be attracted to and collected by the screen. At certain critical voltages the plate secondary emission will *neutralize* the cathode emission. Under these circumstances the plate current actually *decreases* with an increase of plate voltage. Thus, a *negative* resistance characteristic is obtained. This is the opposite of a *positive* resistance characteristic because in the latter the plate current would *increase* as the plate voltage is raised. In the circuit of Fig. 16, the high series impedance in the plate circuit allows the plate potential to *swing* at a certain rate. As the plate voltage increases from a certain point, the secondary emission will lower. As the secondary emission decreases the energy in the tuned circuit will change. The secondary electron flow then will start to increase again.

The electron flow from the cathode is almost entirely independent of plate voltage. However, as the plate voltage *increases,* more secondary electrons will be freed. Up to a certain potential this is true. Above this potential a larger secondary emission will cause a larger flow from the plate to the screen. Under this condition, if a meter were placed in the *plate* circuit a reverse current could be observed from plate to screen. For this condition the number of secondary electrons issued from the plate actually exceeds the number of primary electrons striking the plate. This is the condition known as negative resistance, hence the name *negative resistance oscillator.*

These changes can be controlled by the *tuning* of the plate circuit. This circuit is unstable from a direct current viewpoint and will start oscillating whenever the circuit elements and voltages are properly proportioned.

Excessive resistance in the circuit of any oscillator may prevent oscillation. You probably realize this from your knowledge of the *time factor* in RC circuits. The oscillators described in the preceding are typical of these used in modern super receivers.

OSCILLATOR COUPLING

It is necessary to provide a means by which the RF, produced by an oscillator, may be *injected* or fed into the *first detector or mixer* of a super. This must be accomplished in such a way that the oscillator voltage and the received signal voltage will be combined and rectified at the same time to produce the beat frequency.

A commonly used method is shown in Fig. 17. The received signal having been amplified by the RF stage is *inductively* fed to L2C2. This is the tuned signal input circuit to the *control grid* of the mixer, tube V1. The lower end of L2 is connected to the chassis and thus the signal path is completed to the cathode by resistor R. The voltage drop across R produces the negative bias for the control grid. The signal hetrodyned will affect the plate current in the usual way and there will be an *amplified* signal in the plate circuit. A small pick up coil Lo (very few turns) is *inductively* coupled to the tuned circuit of the oscillator, tube V2. As this *pickup coil* Lo is in series with the *cathode* and bias resistor R of the mixer *any voltage* induced in Lo will be added to or subtracted from the cathode volt-

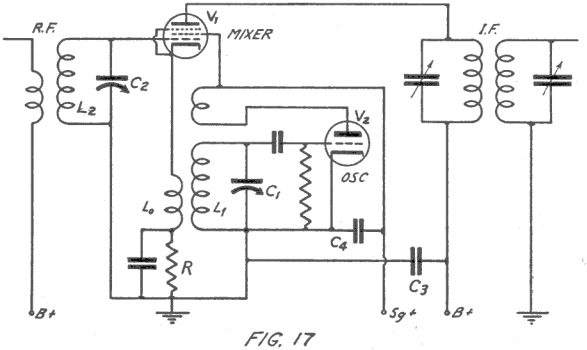


FIG. 17

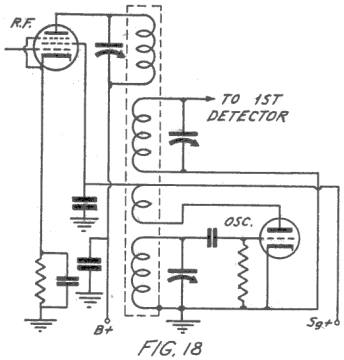


FIG. 18

age. Thus, the frequency generated by the oscillator will modulate (be superimposed upon) the electron stream from the cathode to the plate of the mixer. There need be no other connection between the oscillator and the mixer as sufficient power is generated by the oscillator in L1C1 to induce a voltage in Lo. It is obvious that coil Lo could be inserted in series with any *control* element of the mixer tube and serve the same purpose provided it is coupled properly and by-passed correctly.

The signal is demodulated (original RF carrier removed) because the tube is operating just like the biased detector you have previously studied. The rectified pulses of the signal and the pulses of the oscillator voltage will both be present in the plate circuit of the mixer. The IF transformer in the *plate* circuit of the mixer is tuned to the difference frequency or beat frequency. All other frequencies are lost in the mixer tube and its circuit and only the difference beat frequency or IF is fed to the IF amplifier.

As you may see in Fig. 17, the oscillator operates on a lower plate voltage than the plate of the mixer. The oscillator requires the same voltage as the screen of the mixer. By-pass condensers C3 and C4 prevent interference between the mixer and oscillator.

Another method of *oscillator coupling* is to simply couple the oscillator coils to the mixer tuned grid circuit winding as in Fig. 18. In one shield or can (indicated by the dotted lines in Fig. 18), there are four coils. Two of these are for the primary and secondary of an RF transformer (for the plate of the RF preselector tube and the grid of the mixer tube).

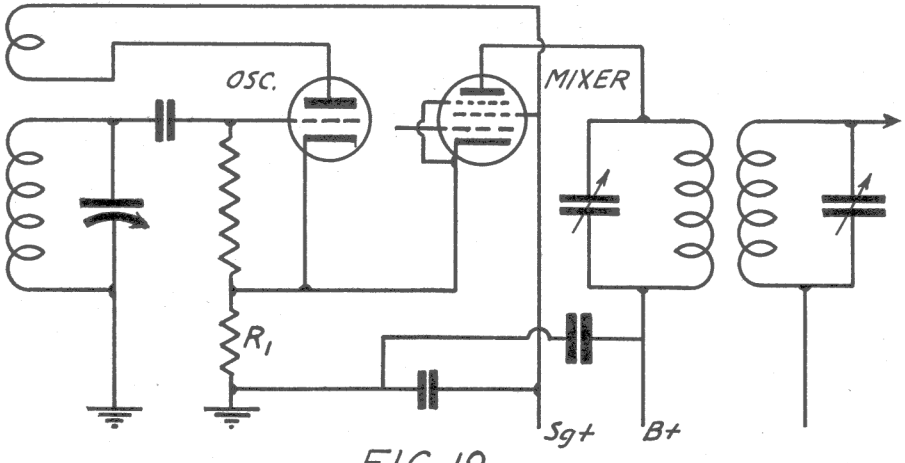


FIG. 19

The other two coils are for the grid and plate of the oscillator. As explained before, the detector or mixer grid circuit cannot possibly be tuned to both the oscillator and signal frequencies at the same time, as they must differ in frequency in order to form a beat note. However, the coupling is fairly close and one circuit has relatively low selectivity of itself so that the oscillator frequency can get into the detector circuit with relative ease. The two signals are fed into the control grid of the detector or mixer tube simultaneously and by detection produce the beat or IF frequency.

Still another method of coupling the oscillator to the mixer is through cathode coupling—by using the type of circuit employed in Fig. 19. Due to the operation of the oscillator, there is an RF voltage drop across the oscillator cathode resistor R1. Plate current for the first detector cathode will have a small voltage fluctuation. This will act on the control grid of the mixer and will cause a small voltage fluctuation in the plate circuit. This variation in the plate circuit will be at the signal frequency and the beat frequency as usual, will appear in the plate tuned coil of the mixer. The IF signal will thus be fed to the IF amplifier. The complete mixer and IF circuits are not shown in Fig. 19 in order to keep the circuit as simple as possible.

COMBINATION CIRCUITS

Early in the progress of improving super receivers it was learned that one tube could be made to operate as *both* oscillator and first detector. Such a tube is commonly called a *frequency converter* or more often simply converter. The methods by which oscillations are produced, in the majority of circuits, comprise chiefly plate to cathode feedback systems. In point to point and aircraft communications, crystal controlled oscillators are used. This latter method is *not* suitable for the usual broadcast receivers as the crystals must be changed for each new received frequency. In circuits in which filament type tubes are used (instead of cathodes) the plate to filament feedback system is used. Where a multi-purpose tube is used as a 1st detector it is a rather simple proposition to combine the two actions. In these cases the cathode (or filament), one grid and the plate are used as an ordinary detector. The cathode, another grid and the plate are used as an oscillator. You may readily see that as the two sections utilize the *same cathode and plate* a *common* electron stream will be *modulated* by both the signal *and* the oscillator frequencies. Thus it is only necessary to have a *tuned* circuit in the plate circuit, adjusted to accept only the difference frequency.

An interesting combination circuit is illustrated in Fig. 20. The signal enters the *grid-leak* detector from the tuned circuit L_3C_4. It is rectified and its average value *corresponding to its modulation* will vary the plate current through L_4. This coil (L_4) is *tuned* and acts merely as a choke coil for the plate and to couple inductively the beat frequency to the IF secondary L_5C_5 which is adjusted to the IF frequency. All but a negligible

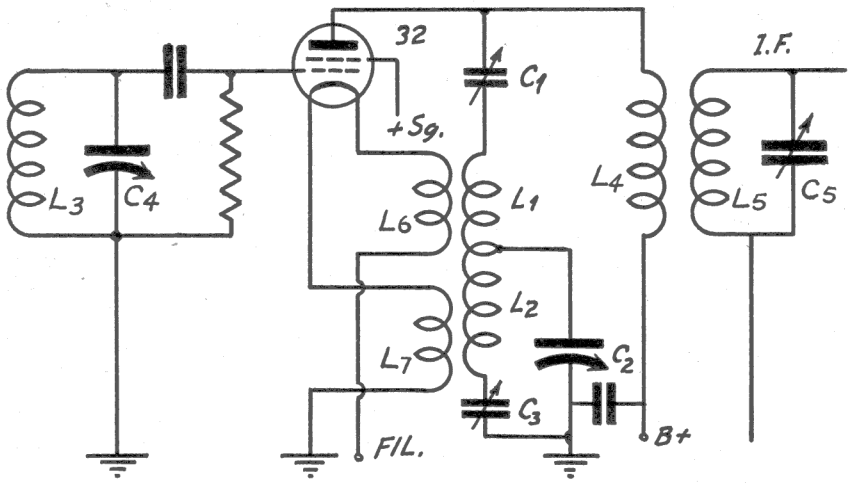


FIG. 20

quantity of all other frequencies present in the plate circuit are rejected by this L_5C_5 tuned circuit.

Referring again to Fig. 20, notice the circuit through C_1, L_1, L_2 and C_3C_2 to ground. L_1 and L_2 are magnetically coupled to two *pick up* coils in the filament leads. These *four* coils are so arranged that a current variation in L_1L_2 will produce an *equal* voltage in each of the filament pick up coils L_6 and L_7. The induced voltages in the pick up coils will always be *of the same potential and polarity* at the filament end of each pick up coil. Thus, the average filament potential relative to ground will change due to these induced voltages. The current *through* the filament, however, will remain constant as no additional current will be induced. This is due to the fact that *no difference* in potential or polarity exists between the filament ends of the two pickup coils *other* than that caused by the current from the filament supply battery.

A fluctuation of voltage in the plate circuit will cause a change in the charge of C_1. This will travel to ground through L_1L_2 and C_2C_3. In passing through L_1L_2 it will induce a change in the pick up coils. This will *change* the relative potential of the filament to plate thus altering the quantity of electrons flowing from cathode (in this case the filament is acting as the cathode) to plate. This, in turn, causes another *surge* in the plate circuit and the whole sequence of events will start again. Since L_1L_2 and C_3C_2 form a tuned circuit, the surges will be timed by this circuit. Because this circuit is tuned to the desired oscillator frequency this frequency will be in the plate circuit where it is *combined* with the signal to form the modulated difference frequency.

In the case of a *cathode* type tube of the RF pentode type, the same action occurs. A typical circuit is shown in Fig. 21. Note that one pick up coil L_1, is needed in the cathode circuit as the cathode in this case has only one lead. The constant bias for making the tube

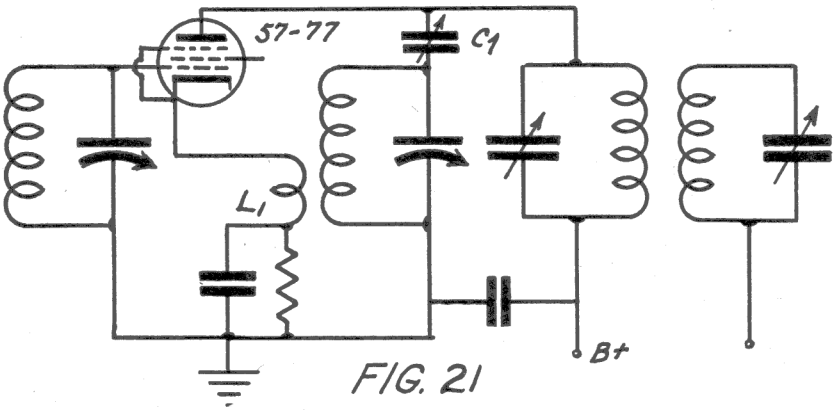


FIG. 21

detect the beat frequency is placed below the pick up coil here, but it is sometimes placed above it. Its position is not extremely important as the two voltages are in series. The feed-back action is the same as that for the tube of Fig. 20. Adjustment of C_1 may be made to regulate the amount of feed-back.

An inductive method of feeding energy from the plate to cathode is shown in Fig. 22, which is a circuit equivalent to Fig. 21. In this circuit a separate plate coil L_1 is in series with the tuned IF transformer to induce voltage into the oscillator resonant circuit. The signal comes into the control grid of the mixer tube as usual and through detection a beat frequency variation is formed in the plate current.

While ordinary tubes, designed for other uses, may and often are used as combination 1st detector-mixers, certain difficulties are encountered. Chief among these difficulties are *shifting* of the oscillator frequency when tuning the RF stage, difficulty in maintenance of oscillation over the entire tuning range and *re-radiation* of the oscillator frequency through the detector input circuit. If the amount of feed-back is increased beyond a certain point, the detector function will cease. Due to the necessity of having a *weak* feedback, the oscillator function is easily disturbed by other changes such as the tuning of the RF input. The weak feedback also results in too great a *variance* in oscillation strength or voltage, when the frequency is changed from the lower to the highest for which it is designed. These troubles led to the development of special mixer-oscillator tubes such as the *pentagrid converter* tubes. These include the 1A6 and 1C6 for 2 volt operation, the 2A7 for 2.5 volt operation and the 6A7 and 6A8 for 6.3 volt operation. Other types for different filament ratings are the 7B8, 7Q7, 6SA7, 12A8, 12SA7, 12K8, 6J8,

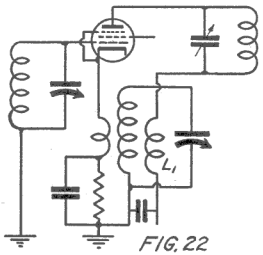


FIG. 22

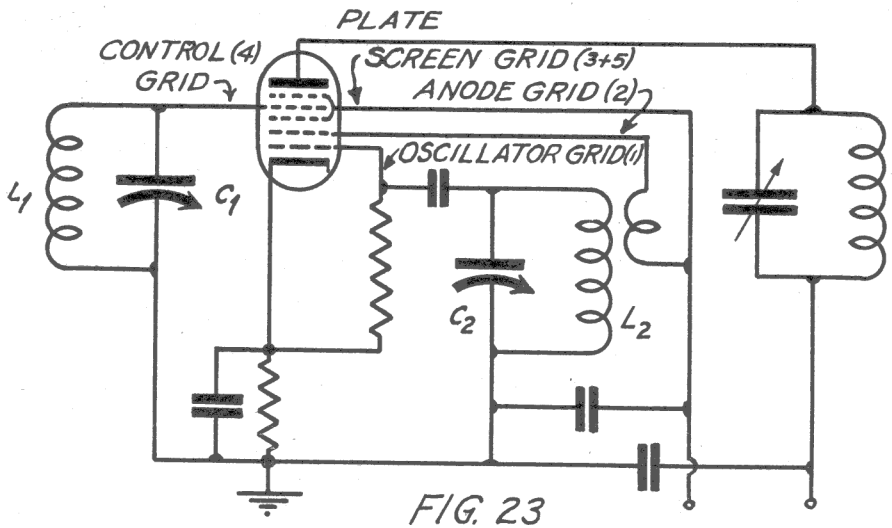


FIG. 23

7J7, 6L7, etc. All of these operate on the same general principles. The only difference between them will be the filament or heater voltage and the D.C. voltage values for which they are designed.

A typical circuit is shown in Fig. 23. With respect to elements of the tube from the cathode, first there is the oscillator *grid* (1), next the *anode grid* (2), then one section of the screen grid (3), the *control grid* (4) and, finally, the outside section of the screen grid (5). The plate is the outermost element. (See any good tube manual).

The oscillator is constructed around the cathode, oscillator grid (1) and anode grid (2). This is just like the triode oscillator in Fig. 7. Instead of collecting all of the electrons, however, the anode grid is an open wire mesh like the control grid allowing pulses of electrons at the frequency of the oscillator grid tuned circuit to fly through it. In series with their path to the plate is the screen (3 and 5) and control grid (4) which allows pulses at the signal frequency to pass through to the plate. The control grid (4) is biased for detection so that as the phase of these two pulses continually shift, first adding and then neutralizing, an intermediate frequency is built up in the outer plate circuit just as for any mixer circuit. The positioning of the elements and the use of the screen allow a sufficient amount of power in the oscillator circuit to maintain oscillation over the entire tuning range without paralyzing the detector action. The internal tube elements are so situated as to reduce to a minimum the effect of one tuned circuit on the other. An important fact in connection with Fig. 23 is that the oscillator section and 1st detector are coupled *by means of the electron stream.* This is commonly called *electron coupling* by use of a converter tube.

The tube is made to provide considerable gain while detecting, but during the process, the signal is *translated* into a different frequency. The characteristic of the tube

to produce a certain intermediate frequency voltage for a given RF signal voltage on the control grid is called the *translation gain* of the tube.

Instead of mutual conductance being a figure of merit for this mode of operation of the tube, it is customary to speak of conductance in transferring the signal from the input to the output while converting it into a different frequency as the *conversion-transconductance* of the tube. This is often symbolized by the letters Sm.

A super circuit must be designed to select the desired carrier, produce a continuous carrier of different frequency than its own, combine these and detect the beat, select and amplify the beat or RF, detect the IF obtaining AF and amplify the AF for reproduction. Each of these will be discussed in order.

The RF part of any super is not unlike that of any tuned RF receiver. It is, in fact, exactly the same thing with simply one or two stages instead of three or four. Before reaching the first detector which rectifies the signal and oscillator frequencies, a considerable degree of selectivity must be obtained as well as adequate sensitivity. The former can only be classified through a study of the IF amplifier and its relation to the detector. The latter is obvious because a certain signal level is required for detection of the bias type.

For the present purpose, assume that circuits A and B of Fig. 6 are sources of radio frequency voltages. You have seen that any two different high frequencies will produce several others among which the *difference frequency only is segregated by the tuned circuits* in the output of the first detector. Furthermore, it is obvious that this different frequency depends not on either high frequency value *but only on their difference.* For example, the same beat or difference frequency may be obtained by cambining 200 and 300 KC as may result by combining 8400 and 8500 KC or 8400 and 8300 KC. The dif ference between the two sets of frequencies is 100 KC in both cases. In addition to this, this difference may be made any value desired as long as it will not interfere with other functions that the receiver must perform. *As one example of this, it is not desirable to let the beat fall within the frequency limits of audibility nor can it be high enough to interfere with incoming signals.* This means that all of the frequency spectrum between 18 and 540 KC is available in which to select a desirable intermediate frequency.

The first super circuits which were used employed intermediate frequencies of 30 KC. Later models used 45, 60, 65, 90 and 105 KC. In present day designs no IF below 100 KC is used,, but values from 175 to 465 are quite prevalent. To determine just why one frequency is preferred to others, you must learn many details about the characteristics of super operation. There follows a list containg several broadcast frequencies with *corresponding oscillator frequencies* required to produce a few of the more common difference beat frequencies.

There are several points in con-

Received Signal	INTERMEDIATE FREQUENCY IF 175 KC	IF 262 KC	IF 370 KC	IF 445 KC	IF 456 KC	IF 460 KC	IF 465 KC
600	775	862	970	1045	1056	1060	1065
800	975	1062	1170	1245	1256	1260	1265
1000	1175	1262	1370	1445	1456	1460	1465
1200	1375	1462	1570	1645	1656	1660	1665
1400	1575	1662	1770	1845	1856	1860	1865

nection with this table which you should study. The local oscillator frequency for each selected IF *must be greater* in value than the incoming signal carrier with which it is combined to form the IF. The IF or beat frequency is equal to the oscillator frequency *minus* the signal frequency in every case. From your previous study, you know that it makes no difference whether the oscillator frequency is above or below the signal frequency as far as the production of a beat frequency is concerned. However, to avoid upper harmonics of the oscillator, for one thing, it is preferable to have the oscillator frequency above the signal frequency rather than below it.

You must deal only with carrier frequencies, not modulation, for the present to determine what accounts for the *great selectivity* of the super circuit. For one particular incoming signal the oscillator is adjusted for example to 1175 KC, and, at the same time, the RF stage or stages or preselector are tuned to 1000 KC. The

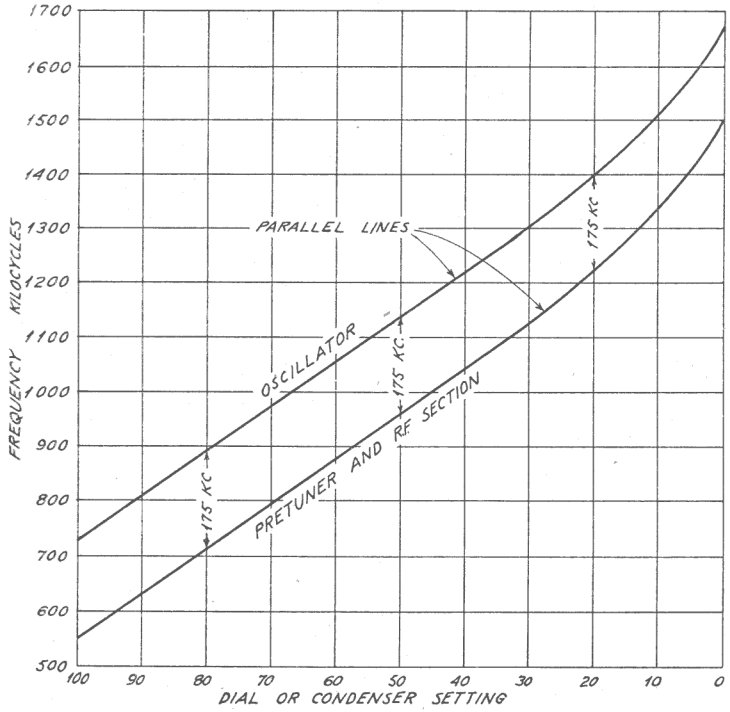


FIG. 24

tuning condenser used for the oscillator stage is ganged with one or two others, and while one circuit is being tuned to one frequency, the other is being tuned to another frequency. However, there should always remain the same frequency difference between the two at any point on the tuning dial. Figure 24 shows the constant frequency separation which must be maintained between the oscillator stage and the RF or preselector stages for an IF of 175 KC.

This relationship or difference in frequency must be maintained for all frequencies that are to be received by the receiver. *The tuned oscillator stage must, in every case, be tuned 175 KC higher* than the signal frequency which is to be received. Study Fig. 24 thoroughly until you are sure you understand this principle. If the IF was some other frequency than 175 KC, the same principle would hold true in that the correct frequency difference should be maintained at all times.

SELECTIVITY FACTORS

The following example will serve to illustrate just why the super circuit gives so much more *selectivity* than do other types of circuits.

Assume that the receiver with an IF of 175 KC is tuned to a frequency of 1000 KC. This means that the RF or preselector stages are tuned to 1000 KC, while the oscillator stage is tuned to 1000 + 175 KC or 1175 KC. Next, suppose a strong 960 KC signal from another station is in the vicinity of the receiver. This signal is only 40 KC (1000−960 KC) away from the frequency to which the receiver is tuned. The combination of 960 and 1175 (the frequency to which the oscillator in the receiver is tuned) will form a beat frequency or IF equal to 1175−960 or 215 KC. Remember the receiver is still tuned to 1000 KC. However, the strong 960 KC signal will get through the pre-selector stages *and will form a beat frequency equal to 215 KC.* This beat frequency is 40 KC away from the frequency to which the IF is tuned (it being tuned to 175 KC).

You have already learned that tuning is largely a matter of percentage or ratio rather than of a fixed or definite value. Consider again, then, this tuning problem from a percentage viewpoint.

The object of any tuning system is to enable the operator of the receiver to tune in *only one signal to the exclusion of all the others.* Unless the wanted signal is free from other signals, it is said the receiver has *low selectivity.* If, on the other hand, the signals are free of interference, it is termed a receiver with *high selectivity.*

The TRF or pre-selector stages in a superheterodyne receiver gives relatively low selectivity because of the *high frequencies* which are involved. This way be easily proven if you will consider the former problem. It was stated that even though the receiver was tuned to 1000 KC a strong 960 KC signal might get through the pre-selector stages. Also, a 215 KC beat frequency would be formed (in the mixer plate circuit) because the local oscillator which is automatically set at 1175 KC will act to produce this beat frequency. Thus, a 215 KC beat frequency as well as

the regular 175 KC beat frequency is presented to the input of the IF amplifier. What is desired, of course, is to *prevent* the 215 KC signal from getting through the IF amplifier. It is effectively accomplished by the inherent high selectivity factor of the IF amplifier.

Now see why the IF amplifier can *reject* the 40 KC *off resonance* signal whereas the RF or pre-selector stages *cannot.*

In the RF stages the 960 KC signal is 40 KC *off resonance* because the receiver is *tuned to 1000 KC.* In order that you may appreciate just what this means, this relation will be expressed as a percentage. 40 KC is only 4% of 1000 KC. Thus, it is seen that if 4% is the selectivity factor, the selectivity must, of necessity, be low. It is also evident that if the resonant frequency is reduced to 175 KC from 1000 KC the selectivity factor will increase if 40 KC remains the *off resonance* factor.

That is exactly what is accomplished in a super circuit. By combining the incoming signal with a local oscillator frequency, the resonant frequency is reduced on account of the beat frequency which is formed.

It has already been stated that because of the 4% selectivity factor in the RF or pre-selector stages, the 960 KC signal forms a 215 KC beat frequency. The resonant frequency of the IF amplifier is 175 KC. 215 KC − 175 KC is equal to 40 KC. Thus the *off resonance* frequency is still equal to 40 KC. *However,* the resonant frequency has been reduced from 1000 KC to 175 KC (remember the IF amplifier is tuned to 175 KC). Under this condition, the selectivity factor has been greatly increased because 40 KC (the off resonance factor) is *22.8% of 175 KC.* Thus in the process of heterodyning the signal from 1000 KC to 175 KC, the selectivity has been increased from 4% to 22.8%.

From this you can see that the IF amplifier has a much better chance of tuning out *unwanted signals* than does the RF amplifier. In fact, a 960 KC signal would not be heard at all even though a 215 KC beat note is formed. However, the regular or wanted 175 KC beat frequency from the 1000 KC signals will get through the IF amplifier because it is resonant to this frequency. The selectivity factor of the usual IF amplifier is so great that the IF amplifier will completely *reject* signals which are even less than 40 KC *off resonance.*

The foregoing examples have been given mainly to illustrate the principle of the super circuit. The numbers that have been used have no particular meaning other than to illustrate these principles. Many other factors are involved in these principles. These will be taken up and thoroughly discussed in your study of the complete super circuit.

It was mentioned that there was no difference as far as the heterodyne was concerned whether a higher or lower frequency was used to form the beat frequency. Suppose instead of changing the oscillator frequency, it was simply considered that a signal is higher than the oscillator frequency.

In the original case it was assumed that the oscillator stage was set to 1175 KC and the RF stages

to 1000 KC. Continue this assumption and further assume that there is another strong signal at 1350 KC —350 KC above 1000 KC. It is obvious that 1350 KC − 1175 KC is equal to 175 KC. Thus, a 1350 KC signal will serve to produce a 175 KC beat frequency just as easily as will a 1000 KC signal. The IF amplifier would, of course, amplify the *new* beat frequency the same as it would amplify the one formed by the 1000 KC signal. In this case, the RF stages are tuned to 1000 KC. The *off resonance* factor in this case is 350 KC. This is 35%. A good RF or preselector system in a superheterodyne must be capable of *rejecting* an interferring signal of more than 35% off resonance to be effective and satisfactory.

In the foregoing examples the signal is 1350 − 1000 = 350 KC apart, but if the 1350 KC signals can reach the signal control grid of the first detector, the 1350 KC signal will interfere with the 1000 KC signal. Then, too, 350 KC is quite a large percentage of frequencies, especially at the low frequency end of the broadcast band, but higher frequencies can skip a complete stage *or can be picked up by the first detector grid lead alone.* For this reason, *good shielding and construction must be used* so that the interfering signal is less than .002% of the desired signal.

For one or more stages in the preselector system there is a definite maximum possible gain. It is desirable to use as few tuned RF stages as possible. This is confirmed by the fact that today only two tuning condensers are used in the preselector of a small super receiver, with an IF of 456 KC so that the interfering signal will be 912 KC (2×456 KC) away from the desired one.

Thus, the first and most important use for *high intermediate frequency values is to prevent or reduce as much as possible the danger of receiving signal frequencies that are above the oscillator frequency by an amount equal to the same value of the IF.* For a given selectivity, there is much less possibility of receiving the undesirable signal than with a lower IF.

For example, with an IF of 130 KC, an undesired signal just 260 KC away from the desired one would be subject to reception. The preselector would have to select very carefully between the desired and undesired signals in this case. If all of the tuned circuits in the entire receiver precede the first detector, it would be quite a simple matter to obtain even a much greater selectivity than this, but the value of the super circuit would be lost. Therefore only a portion of the total selectivity may be acquired before the first detector. In many cases only one tuned circuit is used and, in some cases, two are used. Very rarely are there three preselector circuits used ahead of the mixer tube. (Sometimes three RF stages are used in expensive receivers).

If the IF is increased to 465 KC, the undesired signal will be shifted up to 2×465 or 930 KC above the desired signal. When the receiver is tuned to, say, 1000 KC, it is evident that 1930 KC (1000+ 930) will be almost 100% higher and very considerably out of resonance away from 1000 KC. How-

ever, if the IF is as low as 130 KC, an undesired signal of 1000+ (2 ×130) or 1260 KC is only 26% higher and is more nearly in tune with the 1000 KC circuit than for the first example. At the point of resonance the desired signal should have 50,000 times the strength of the undesired signal in order that no interference will result.

You are now ready to give further and more detailed study to the first detector or mixer circuit. In the first part of this lesson, it was shown how two unmodulated frequencies combine to form others. At this point, you will very probably want to know how a *modulated* carrier frequency combines with an *unmodulated* oscillator frequency to *form a modulated difference or beat frequency.* In other words, you will learn how the modulation carried by the high frequency is *translated* to intermediate frequency.

A series of graphs show this situation step by step in as logical a proportion as can be conveniently drawn in Fig. 25. Illustrated at A is the generated oscillator voltage as it would appear on the mixer grid. Its frequency is 1175 KC, and note carefully that it is *unmodulated.* Each successive voltage peak is the same height as all the others in both the positive and negative direction.

At B of Fig. 25 is shown a received signal which has a carrier frequency of 1000 KC and a 1000 cycle modulation frequency. Note that the slightly lower frequency than the oscillator is indicated by the individual cycles being spaced a little greater than for the unmodulated oscillator frequency.

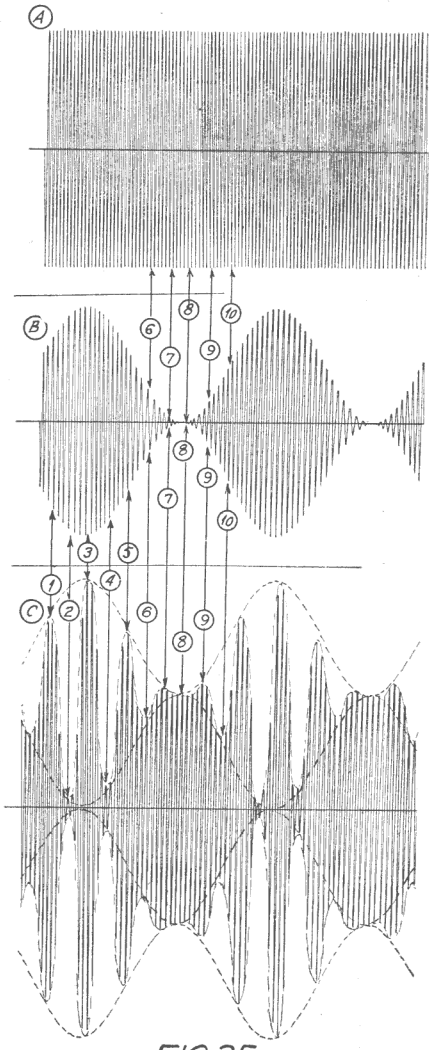


FIG.25

Note also at B of Fig. 25 that the amplitude of the individual carrier voltage cycles vary in accordance with the 1000 cycle modulation. Enough of the signal carrier is shown to form two cycles of the modulation.

At C in Fig. 25 the compound wave is illustrated which demands very close study. Along the direction of the time axis, numbers are placed for reference. At No. 1,

the carrier (B) and oscillator (A) voltages are exactly in phase and they add thus forming one cycle of the compound wave (C) equal in amplitude to their sum. From 1 to 2 they gradually shift phase because the oscillator peaks occur 1.175 times more often per second than the signal peaks. At point 2 at C of Fig. 25, these two waves, A and B, are exactly out of phase and they cancel each other partially. Here the carrier voltage is not quite as great as the oscillator voltage and hence there remains a small amount of oscillator energy which the signal has not neutralized.

At point 3 in Fig. 25 (C) the two waves are again in phase and this time the signal is just a little beyond its maximum height. The voltages now add, making a peak equal to their sum. Arriving at point 6, the two are again out of phase, but the signal voltage is now somewhat lower than it was before and only partial cancellation will result. At point 8 the signal voltage has dropped to zero because of the trough in the audio cycle which is modulating it. Therefore the only voltage acting on the mixer grid is the oscillator voltages as shown at the same amplitude as in (A).

When the two waves (oscillator and signal) are in phase, they form a peak as at points 1, 3, 5, 7, 9, etc. (see C of Fig. 25, but when they are out of phase, they form troughs as at points 2, 4, 6, 8 and 10 of Fig. 25. These peaks occur every 175,000th of a second and thus form the intermediate frequency. Where the signal carrier is strong, such as at 2 and 3, the intermediate frequency is strong. Where the signal is of low intensity—its addition and subtraction from the oscillator voltage diminishes and there is less IF. The amount of the IF voltage is, therefore, proportional to the amount of carrier voltage at any instant and this, of course, is controlled by the amount of modulation on the carrier.

The compound wave at C of Fig. 25 contains the resultant of the carrier and oscillator frequencies, the intermediate frequency and the audio frequency. However, the plate circuit is tuned only to the IF. The detector action cuts off the lower half of this entire wave below the horizontal straight line in Fig. 25C, leaving only the top half. This consists of voltage pulses building up the IF and these IF pulses trace only the IF—the RF being by-passed by the first IF tuning condenser and the audio remaining as a variation in amplitude of the IF peaks. The grid voltage for the first IF amplifier will, therefore, look like the curve of Fig. 25D. Note that the IF is now carrying the audio voltage exactly as the RF carrier did at B, although the IF is a lower *carrier* frequency.

This wave, Fig. 25D, is again rectified (detected) at the second detector, obtaining the audio voltage as at E of Fig. 25.

It is suggested that you study Fig. 25 once and then lay it aside for a while. Then come back to it and study it again. If necessary, do this several times until you grasp the idea. Such concepts as this are rarely understood by many men who have studied radio off and

on for many years. This subject is usually avoided except in mathematical treatment. To be able to see this action graphically will allow you to see precisely what takes place and to judge what would happen if one of the frequencies changes, if the amplitude of one or the other changes, or if other things are varied. You can see why a mixer or first detector is used instead of simply an amplifier, which fact is little known among radio men. In wave C of Fig. 25 you can plainly see that cancellation would result if an attempt were made to amplify this entire wave without rectification. The resultant high frequency wave could be amplified with a broadly tuned amplifier but it would not be possible to obtain the desired selectivity in this way.

In the next lesson you will study other principles of the superheterodyne. Also a following lesson will treat a complete superheterodyne circuit. You are urged to study this lesson in careful detail before you pass on to the next one.

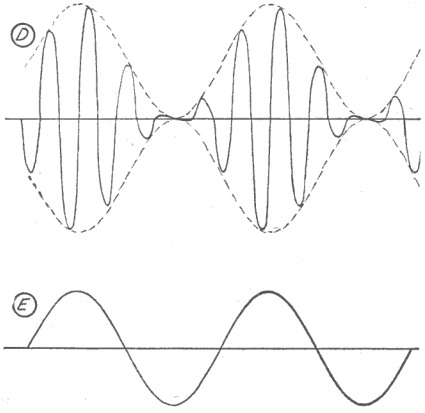


FIG.25

These questions are designed to test your knowledge of this lesson. Read them over first to see if you can answer them. If you feel confident that you can, then write out your answers, numbering them to correspond to the questions. If you are not confident that you can answer the questions, re-study the lesson one or more times before writing out your answers. Be sure to answer every question, for if you fail to answer a question, it will reduce your grade on this lesson. When all questions have been answered, mail them to us for grading.

QUESTIONS

No. 1. What additional frequencies can be obtained by rectifying two different frequencies simultaneously and what relation have they to the original frequencies producing them?

No. 2. Could a superheterodyne work properly using an amplifier instead of a first detector?

No. 3. Why is it that a crystal controlled oscillator is not used in modern broadcast superheterodyne receivers?

No. 4. What is the greatest advantage of using a fixed frequency tuned amplifier as in the superheterodyne compared to the variable frequency tuned amplifier in the TRF receiver?

No. 5. How are the oscillator and first detector coupled in the pentagrid converter circuit of Fig. 23?

No. 6. In the modern receiver is the oscillator frequency generally above the signal frequency or below it?

No. 7. Why is a grid leak used to bias an oscillator rather than a cathode resistor as for an amplifier?

No. 8. What part of a superheterodyne receiver provides its highest percentage of selectivity?

No. 9. What method is used to prevent reception of signals above the oscillator frequency by an amount equal to the IF?

No. 10. What type of energy is supplied by the local oscillator in a superheterodyne receiver?